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http://geodesy.unr.edu/magnet.php

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Abstract

In this project we took the University of Nevada's Mobile Array of GPS for Nevada Transtension (MAGNET) to a new stage of network operations and geodetic observation. With support from the USGS Geodetic Networks program we implemented transformative changes to MAGNET that improved coverage in each of three major categories. First, we continued to improve constraint on secular motion of MAGNET stations in the western Great Basin, extending the duration of time series and reducing uncertainties leading to improved understanding of the rates of crustal strain and uplift. Second, we improved understanding of the relationship between tectonics and earthquake processes by responding to significant earthquakes and vigorous swarms inside the MAGNET footprint. Third, using support from two supplemental awards we initiated a sub-network for MAGNET that is essentially continuous. This means that for 31 stations the GPS receivers remain at the same location all of the time, unlike in the rest of MAGNET where the receivers move from station to station throughout the year. This phase of the project has resulted in a more modern portfolio of instrumentation in the network, has increased the number of active receivers in MAGNET to 80, thereby increasing the number of daily files that are recorded and provided to the community. The upgrade also increased the temporal continuity of observation at some locations, and increased the flexibility of MAGNET to respond to earthquakes.

The introduction of new, improved and robust analysis strategies has improved the accuracy and quality of our maps of the rate of crustal movement, in both the horizontal and vertical components. These methods, including improved GPS data processing, have enabled us explore scientific topics such as the relationship between geologic and geodetic data in the Central Walker Lane, uplift of the Sierra Nevada, time-variability of deformation owing to seasonal to drought-driven changes in surface loading, and their impacts on magmatic inflation at the Long Valley Caldera magmatic system. Over the recent project period MAGNET was involved in geodetic responses to a number of seismic events, including the 2014-2015 Sheldon earthquake swarm in northwest Nevada, the 2016 Nine Mile Ranch sequence in the Central Walker Lane, the July 2019 Ridgecrest sequence, the March 2020 Carson City M4.5 earthquake, the April 2020 Mono Lake sequence, and the 2020 Monte Cristo Range M6.5 earthquake. Owing to recent USGS requirement for immediate data availability without embargo we now place all MAGNET RINEX data on http://geodesy.unr.edu for immediate free and open access as soon as it enters our archive.

Report

Introduction

The Mobile Array of GPS for Nevada Transtension (MAGNET) is a network of geodetic markers that is comprised of small steel pins in stable rock formations, usually bedrock. The position of these monuments are measured precisely and tracked over time to reveal the rate, pattern and style of crustal deformation in the western Great Basin. We use precise GPS measurements to obtain the positions, from a fleet of instruments that has grown to 80 receivers since the Nevada Geodetic Laboratory (NGL) starting recording data in the network on January 30, 2004.

Currently there are over 400 MAGNET stations distributed at approximately 20 km spacing in western Nevada, eastern California, with a few in Arizona, Utah, and Oregon (Figure 1). The stations are, except for a few, not telemetered and require visitation to install the stations with remote solar power and retrieve data from compact flash memory. In this 5 year cooperative agreement we collected data at MAGNET stations to lengthen time series, reduce the uncertainties in rates of crustal deformation, constrain coseismic deformation, study uplift of the Sierra Nevada, and magmatic inflation at the Long Valley Caldera (LVC). Site locations and equipment used to survey the sites are detailed in Tables 1, 2 and 3.

All MAGNET data are shared free of charge and with open access. We accomplish this by placing all the data into the UNAVCO archive within three months of collection. Additionally, in order to make MAGNET data available with greater ease and lower latency, we make the data available via our own web server (http://geodesy.unr.edu) immediately upon arriving in our laboratory.

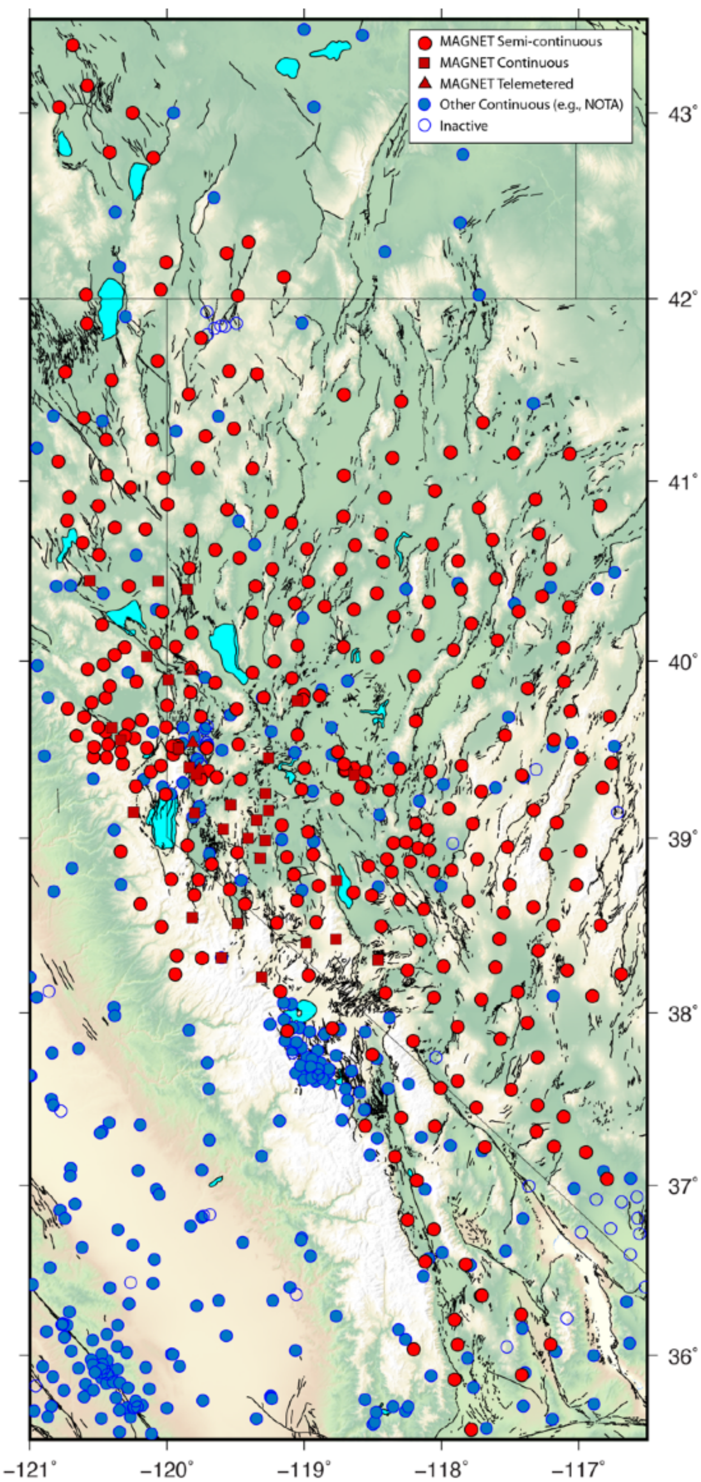

Figure 1 (left). Portion of the MAGNET GPS Network that lies in the western Great Basin. Blue = continuous stations of other GPS networks, including UNAVCO's Network of the Americas (NOTA), red circles = MAGNET, dark red squares = MAGNET continuous stations, dark red triangles = telemetered MAGNET.

Data Collection in MAGNET

Data collection in MAGNET network has been predominantly in semi-continuous mode since its inception. This means that GPS receivers are moved from station to station, staying in one place for one to several months, or longer as logistical and observation needs arise. In theory all available receivers are recording data at all times (so the network is in a way continuous). While the spatial coverage varies over time and temporal coverage appears incomplete at individual stations, the flexibility of MAGNET is that much more territory can be covered (Figure 1) on fixed costs. Most of the work of moving receivers from station to station is accomplished by Nevada Bureau of Mines and Geology Development Technician Bret Pecoraro, who visits stations with our dedicated geodesy Ford F350 (Figure 2). Bret retrieves the data, moves the receivers, and makes repairs and adjustments as necessary, performs preliminary data formatting, archiving and error checking.

Over the calendar years of 2015-2019 we collected 108,464 total days of RINEX data that are now available for analysis. A median of 22,257 days per year were collected, or ~61 files per day. In any given year since 2005 we have surveyed between 151 and 257 MAGNET stations in that year. In 2018, for example, we collected 25,070 days of data at 187 stations for an average of 134 days (37% temporal coverage for that year) at stations that were surveyed (but 0% at others). Selection of which stations are surveyed in a given year depends on scientific opportunities, earthquake response needs, prior history of surveying (stations with greater need of data are surveyed more) to maximize coverage of mature crustal velocities, and logistical factors.

Figure 2 (above) Essential equipment of the MAGNET GPS Network. Lower left) Ford F350 with security shell, Upper left) Zephyr Geodetic antenna deployed at MAGNET station. Lower right) Septentrio PolaRx5e receiver (inside box), with solar panel and Veraphase 6000 antenna. Upper right) another view of MAGNET deployment with solar panel and plastic box containing receiver and other components.

Telemetered Stations

NGL now operates three MAGNET stations that collect data continuously and are also telemetered to send data using using the Nevada Seismological Laboratory (NSL) digital private

IP network. These stations are LMRR, WVRT and RDFD. These stations have MAGNET style monuments, though LMRR is on top of a building on the UNR campus. Each of them are collocated with NSL seismic stations and piggy back on their telecommunications. NGL downloads the data and processes them in concert with all the other MAGNET data. Their locations are shown in Figure 1. The time series for these stations are more complete and their data available with lower latency.

Continuous Stations - Results from Supplemental Funding

In 2018 and 2019 UNR was awarded supplemental funds to modernize equipment within the MAGNET network. These funds were used primarily to purchase new GPS receivers to address MAGNET's aging pool of Trimble R7s and 5700s. While many of these receivers are still performing in the field and returning high quality time series, they are beginning to have selective component failures and are no longer supported by Trimble or serviced by UNAVCO. With the first supplement we purchased 9 Trimble Net R9 receivers. These were discontinued by Trimble the following year, so in the 2019 supplement we purchased 12 Septentrio PolaRx5e receivers, similar to the models used by UNAVCO for Network of the Americas (NOTA) stations. All of these receivers from both the first and second supplements except for 2 have been deployed to MAGNET stations relatively near to our offices in Reno, NV, (Figure 1). The two that have not been yet deployed to the field will go into locations on which we are awaiting permitting actions. However the equipment has already been purchased, assembled and is ready to go into the field. The new receivers have been deployed to stations that we now consider continuous so are visited periodically to download the data but not move the equipment. We have already returned data from the new Septentrio receivers and confirmed that their data have processed correctly in our system, and have time series with low RMS scatter. There are now 30 MAGNET stations that are considered continuous.

Tables of MAGNET station locations and DOI information are available online at:
http://geodesy.unr.edu/magnet/Table1web.html

Tables of MAGNET instrumentation and monument information are available online at:
http://geodesy.unr.edu/magnet/Table2web.html

Data Processing

All MAGNET data are included in NGL's GPS data processing system, which currently contains data for over 18,000 stations from many networks around the world (Blewitt et al., 2018). The system is based on the latest version of the GIPSY/OASIS software (GipsyX - Version 1.0), used in precise positioning mode (Zumberge et al., 1997) to estimate daily and 5 minute station coordinates. Our version includes all the recent software updates, models, satellite orbits, clock files, and other products from the Jet Propulsion Laboratory (JPL) aligned to the IGS14 reference frame (ITRF14 - Altamimi et al., 2016).

In 2019 we completed a reprocessing the entirety of our GPS data holdings. The processing was completed on our own servers over 3 months' time in parallel with our ongoing operational processing, and so was achieved without interrupting ongoing production of time series. The result is that we now have all solutions in ITRF14 and these have been released on our data products system (http://geodesy.unr.edu) for general use. A detailed description of the data processing methodology and underlying models is available at http://geodesy.unr.edu/gps/ngl.acn.txt. Studies are now ongoing to assess the impact that the update has had on the solutions (Blewitt et al., 2019; Martens et al., 2020), but early results show that RMS residual scatter of the time series has been reduced by 17%, and even more for the vertical component (Blewitt et al., 2019).

Once the time series are generated in the IGS14 reference frame and they are subsequently aligned to various plate-fixed reference frames for the convenience of users on various continents. The alignment to plates is achieved by subtracting the trend (not applying a daily filter) predicted by the Euler rotation vectors of the plate as derived in Kreemer et al. (2014). The vertical time series are not affected by this rotation. For MAGNET data the relevant frame is the North America (NA) plate, and so all MAGNET time series are provided in both IGS14 and NA plate-fixed frames. An example of a resulting MAGNET time series compared to that of a nearby station of the NOTA network is shown in Figure 3.

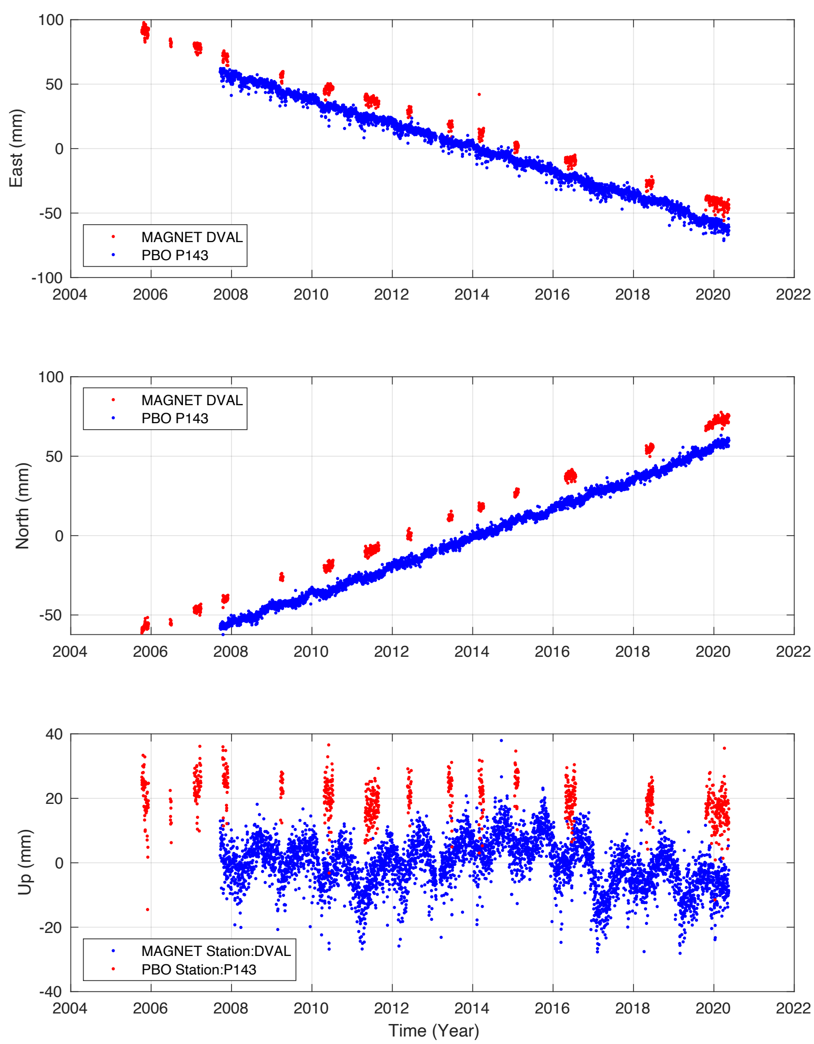

Figure 3 (left) Example time series from MAGNET station DVAL (red dots) compared to UNAVCO operated NOTA station P143 (blue dots) installed about two years later. These stations are near the California/Nevada border south of Gardnerville, separated by about 600 meters. The horizontal time series (top and middle) show that both stations provide data with very similar trends, while the vertical time series (bottom) show they have very similar internal signal and noise structures. This indicates that MAGNET has effectively resolved rates of tectonic motion and time-variable deformation that are discussed below.

The latency of time series products is driven by the latency of availability of JPL products needed for GIPSY processing, namely the GPS satellite orbit, clock and transformation parameter files. These come in final (latency about 2 weeks), rapid (latency next day) and ultrarapid (latency ~1.5 hours). We produce solution sample rates of 5 minute and 24 hours in separate files. More details on the latency of the different products are found below and at http://geodesy.unr.edu/gps/ngl.acn.txt.

Final Solutions are generated using JPL's final orbit products, for 18,772 stations including MAGNET, in both 24 hour and 5 minute data intervals. These solutions are available after roughly two weeks, the latency on the final orbits. We update these solutions weekly, and the web pages and all products are regenerated daily to keep pace with the new solutions, including the rapid solutions that are discussed below.

Rapid Solutions. We currently provide solutions based on JPL's rapid orbits (~1 day latency) for 10,768 stations around the world including MAGNET. While MAGNET data not received via telemetry they are ofter retrieved quickly through field operations after earthquakes and arrive in our laboratory before final orbits are ready. Thus these solutions are often available shortly after earthquakes and can be used to rapidly estimate coseismic displacements, characterize the slip, assess early postseismic deformation, support InSAR work, etc. A solution for the previous day is usually available by 9 am the following day. These are aligned to a global reference frame defined by JPL rapid orbits, which are generated by holding fiducial stations fixed to IGS14. See http://geodesy.unr.edu/NGLStationPages/RapidStationList for a list of stations for which rapid solutions are available.

Rapid 5-minute solutions. For all stations with rapid solutions we provide 5-minute solutions as well. Using these time series we have successfully estimated displacements from large earthquakes the day after the events, including the July 2019 Ridgecrest and May 15, 2020 Monte Cristo Range earthquakes.

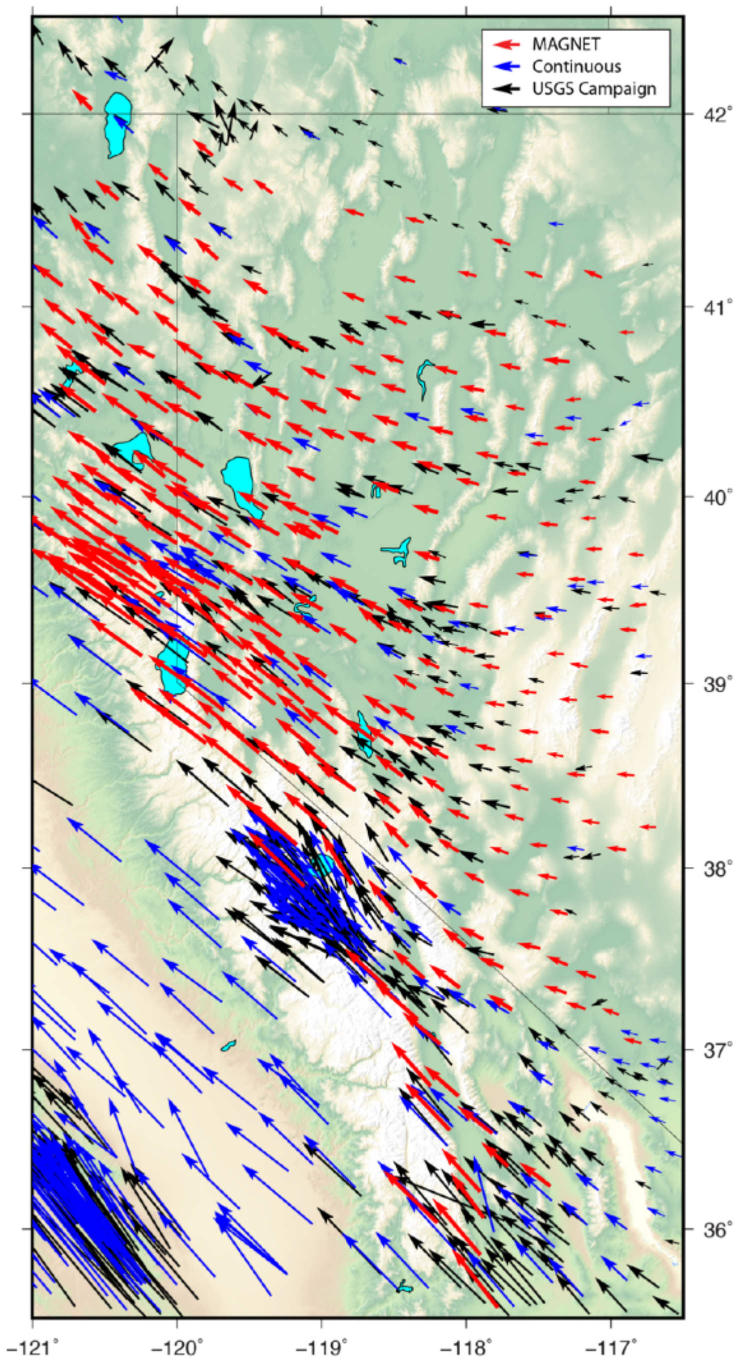

Figure 4 (left) MAGNET GPS velocity field in California and Nevada, western Great Basin, showing horizontal GPS velocities (red vectors) with respect to North America reference frame). Blue vectors are MIDAS velocities for continuous GPS stations processed by NGL. Black vectors are velocities from USGS campaign GPS networks obtained from USGS web pages (see text for link).

Ultrarapid solutions. We provide solutions for up to ~1500 stations using ultrarapid orbits from JPL that have ~1.5 hour latency. These solutions provide 5-minute sample interval time series that are updated every hour and appear on the station pages. For a list of stations that have 5 minute ultrarapid solutions see http://geodesy.unr.edu/NGLStationPages/UltraStationList. While these solutions do have some excursions in their time series, especially near day boundaries at midnights, they will be able to reveal very large displacements shortly after large ground moving events.

MAGNET Velocity Field

To derive a velocity field from the MAGNET data we use the MIDAS robust trend estimator which was developed in part to deal with features in MAGNET data (Blewitt et al., 2016). MIDAS does not use least squares to estimate the time series trend. Instead it employs Thiel-Sen statistics to select the modal trend from pairs of observations in the time series that are separated by a nominal duration of 1 year. This solution has the property that it is relatively immune to bias from discontinuity steps (documented or not) in the data as long as there are not too many. The estimator is also insensitive to seasonal signals owing to it being based on pairs separated by one year.

Every week we apply MIDAS to all time series data in NGL's GPS holdings, for each plate-fixed frame, and post the solutions on our web page http://geodesy.unr.edu. The MAGNET velocity field for the western Great Basin in shown in Figure 4, where it can be compared to the MIDAS velocity for other continuous stations processed by NGL and compared to USGS campaign velocity fields available at https://earthquake.usgs.gov/monitoring/gps. Here it can be seen that the MAGNET network fills large gaps in the continuous and USGS campaign stations, and provides a velocity field that is smooth and relatively free of outliers.

A table of the MIDAS velocity field specifically for MAGNET stations is always available online at: http://geodesy.unr.edu/magnet/Table3web.html

Project Data Products Distribution

MAGNET Network Information Website: http://geodesy.unr.edu/magnet.php

All data collected by NGL at MAGNET GPS stations are converted to RINEX format files and are backed up on internal computer disks at several locations within NGL. On a quarterly basis the files are transferred to UNAVCO for permanent archiving and community access through the Geodesy Seamless Archive (GSAC) and Data Archive Interface (DAI - https://www.unavco.org/data/gps-gnss/data-access-methods/dai2/app/dai2.html). In May 2020 NGL has begun to additionally provide MAGNET data immediately upon its conversion to RINEX by placing it on our own web server at http://geodesy.unr.edu/magnet/rinex. Thus all community members will be able to access MAGNET data as soon as possible.

MAGNET Station Pages

Data products based on MAGNET data are organized via the USGS-required project tables at http://geodesy.unr.edu/magnet.php. These tables have links to the station pages which provide detailed information about the stations and their data products.

After time series text files are generated in the NGL processing system they are posted on our data products server and are available for viewing and download. We provide time series in both east, north, up and x, y, z coordinate systems. Readme text files are supplied to describe the files contents and formats. These files exist on our servers as text file resources that can be downloaded via scripts and integrated into project workflows with, e.g., *wget* or *curl* commands. Graphics of the time series generated with the GMT software are provided and can be downloaded as .png files. All MAGNET time series are currently provided in IGS14 and North America reference frames. We generate "cleaned" time series with outlier and large uncertainty positions removed and present them graphically. We also generate detrended time series (with the MIDAS trends removed) to so that structure of the time series can be seen. These viewing options are useful for better viewing the content of the time series when large trends or outliers exist.

The time series are presented in station pages which have distinct URLs for each station (e.g. http://geodesy.unr.edu/NGLStationPages/stations/RENO.sta) and organize information that is relevant to the station. The station pages are made discoverable via hyperlinked Google maps, hyperlinked tables, and list-based files on our data products pages. The station pages summarize the time series that are available for the station, and also metadata such as nominal coordinates, operator information, and a Google map pane that shows the station location.

For each time series a provisional, automatically generated model is derived and is plotted as a red line on the graphical plots. The model assumes the MIDAS velocity, but solves via damped least squares for other parameters. These include the intercept, step amplitudes (based on the discontinuity table discussed below), the amplitude of annual and semi-annual sine and cosine oscillations, and postseismic transient terms after large earthquakes. When the MIDAS trend is not available for a station, least squares is used to estimate the trend. In cases where a large earthquake (M>6.9) has occurred near enough to the station we solve for an exponential decay function with a form of $A(1-exp(-(t-t_0)/\tau))H(t-t_0)$ where t_0 is the time of the earthquake, τ is a relaxation time, A is the amplitude of the decay, and H is the Heaviside step function. In these cases we re-solve for the background trend after the exponential terms have been obtained to derive a self-consistent model for the time series. The graphics are generated using the GMT software (Wessel et al., 2013), and provided in .png format.

Every station page has a link to the Quality Assurance (QA) information that is generated as a part of the GPS data processing. These files are valuable when hunting down the source of problems if issues arise with the data processing. The guide for the QA files provides information about the structure and derivation of the records and is available at http://geodesy.unr.edu/gps_timeseries/QA.pdf.

Recently we have upgraded our data products system to present Digital Object Identifier (DOI) information for every MAGNET station, both in a table on the MAGNET project page and at the top of each relevant station page. This way the data can be cited with the DOIs that are hosted by UNAVCO. Every DOI listed has a direct link to the UNAVCO DOI summary page for the station.

Discontinuity Table

As part of our data products we keep a list of potential step discontinuities for every station including MAGNET. These are tabulated and made available in a single text file (http://geodesy.unr.edu/NGLStationPages/steps.txt) on our website. These records indicate *potential* steps because we recognize that the detectability of a step in GPS time series is a function of the analysis method used to estimate its size, in addition to the actual amount of movement. Therefore, we create an entry in the database for a station and time where an earthquake or GPS equipment event *potentially* moved the station.

For every earthquake over M 5.5 we compute a radius of influence ***r*** using the formula ***r*** = 10^(***M***/2 - 0.8) where ***M*** is earthquake magnitude. When an earthquake is within this distance to the station an entry is placed in the steps.txt file and on the station page. The record indicates the event date, magnitude, distance to the station, and provides a link to the USGS event page keyed by its unique event ID (e.g. https://earthquake.usgs.gov/earthquakes/eventpage/ci38457511/executive for the Ridgecrest earthquake on July 6, 2019).

For equipment-related steps, there are relatively few in MAGNET compared to continuous stations because we endeavor to keep equipment type the same for all surveys for a given station. However, there are a few exceptions, so we generate IGS-style site logs for every MAGNET station and provide these online at http://geodesy.unr.edu/magnet/logs/. We use software to sift information from these site logs to identify antenna or receiver change events that should be marked as a step, similar to how we treat log files from all other networks. Based on the identified dates we make entries into our steps database. These include only equipment events that result in a substantive change in equipment type (e.g., not changes in equipment of the same type).

Other Products

In addition to the results from processing of GPS station RINEX files, we now provide online summary tables of all stations processed. These tables are in text format, suitable for automated machine reading, and are updated daily to reflect new stations, data, solutions and time series duration.

List of all GPS station names, latitude, longitude and height:

- http://geodesy.unr.edu/NGLStationPages/llh.out

Lists of all GPS data holdings are available for each form of solution latency and sample rate:

- http://geodesy.unr.edu/NGLStationPages/DataHoldings.txt
- http://geodesy.unr.edu/NGLStationPages/DataHoldingsRapid5min.txt
- http://geodesy.unr.edu/NGLStationPages/DataHoldingsRapid24hr.txt
- http://geodesy.unr.edu/NGLStationPages/DataHoldingsUltra5min.txt

Results Obtained - Significant Contributions

Maintaining a geodetic network in the western Great Basin has resulted in improved understanding of various active processes in and around the Walker Lane, Sierra Nevada, and Long Valley Caldera. We divide the contributions into three categories, 1) tectonic deformation, fault slip and hazard, 2) uplift of the Sierra Nevada and hydrological loading, including Long Valley Caldera magmatic inflation, 3) earthquakes illuminated by rapid response to constrain pre-, co- and post-seismic deformation of events that occur inside the MAGNET network footprint.

We used MAGNET to chart with new accuracy and detail the rates, patterns and styles of fault slip in the central Walker Lane. In the study of Bormann et al*.,* (2016) we used the velocity data to address an important discrepancy between geologic and geodetic data, where insufficient strike slip has been observed in neotectonic investigations to account for the shear deformation observed with geodesy (Wesnousky et al., 2012). Bormann tested models that allowed and disallowed active strike slip in the central Walker Lane basins. She found that models that disallowed strike slip could not be made to be consistent with the GPS data even if the blocks were allowed to rotate on vertical axes. The conclusion was that some structures that accommodate strike slip need to exist in the basins to account for the geodetic shear, though these had not yet been discovered by geologists. At least one discovery of a strike slip fault has been made (Dong et al., 2014) but is in itself not sufficient to explain the discrepancy. Searches for the missing strike slip continue (Pierce et al., 2019).

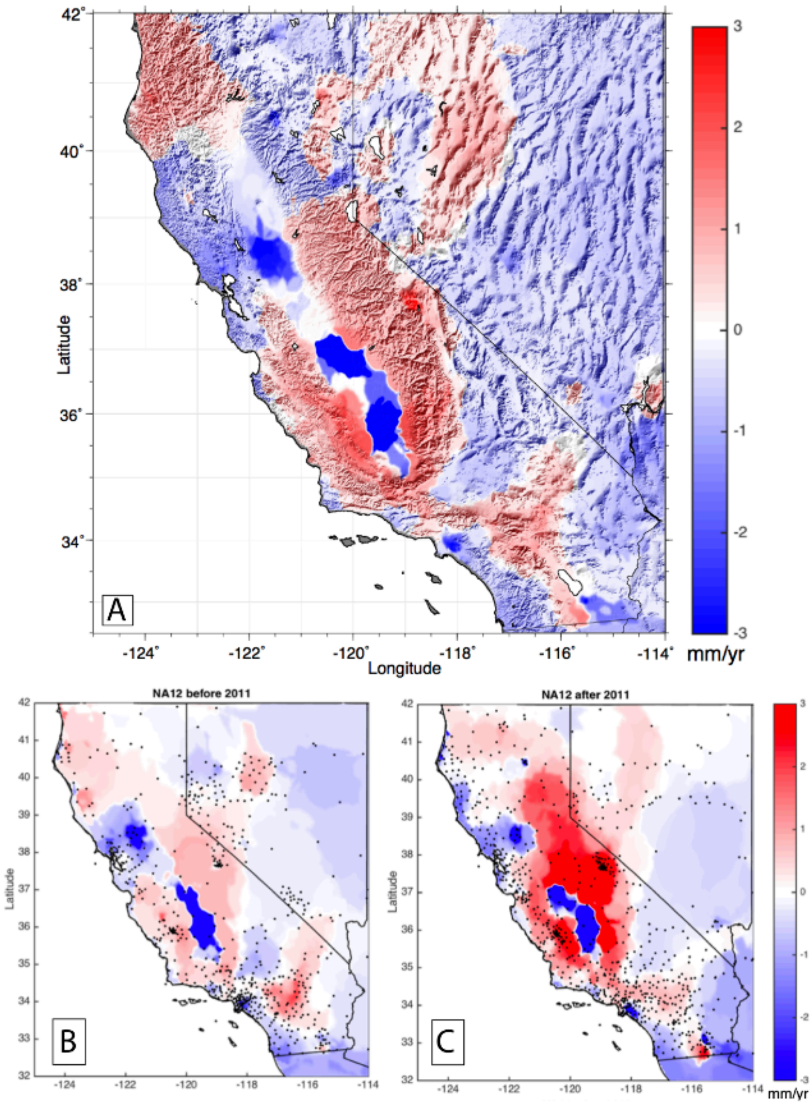

Figure 5 (above). A) Vertical GPS velocity from robust non-parametric estimation, using weighted median spatial filtering and interpolation, known as GPS Imaging, of Sierra Nevada uplift and postseismic relaxation from the CSNB (Hammond et al., 2016). B) Same but with data collected prior to 2011.0, C) with data collected 2011.0 to 2016 indicating the increased uplift rate during drought period in California.

Constraints on vertical motions of the Sierra Nevada and Great Basin have improved because of 1) the geographic coverage and precision of geodetic networks including MAGNET, 2) improvements in processing and analysis techniques. Images of vertical motions have revealed uplift along the entire length of the of the Sierra Nevada, and viscoelastic postseismic uplift associated with the 20th century earthquakes of the Central Nevada Seismic Belt (CNSB) and southern Mojave Desert (Figure 5). The time-variable nature of the uplift has shown the sensitivity of the motion to surface loading from hydrological conditions. These conditions change over seasonal (Argus et al., 2014; Kreemer and Zaliapin, 2018; Johnson et al., 2017) and multi-annual time frames, e.g., from droughts and wet periods (Hammond et al., 2016). These loads have an affect on horizontal displacements, stress in the Earth, and seismicity and so will be the subject of continued future research.

An example of how the loading can have geophysical and hazard significance is how the drought has influenced magmatic inflation at the Long Valley Caldera (LVC) near Mammoth California in the Central Walker Lane (Figure 6). With a combination of MAGNET and continuous GPS data we showed that inflation at LVC accelerated during the drought period, and that the related horizontal ‘transient’ deformation could affect the occurrence of moderate earthquakes up to 80 km from the center of the caldera (Hammond et al., 2019). The drought-triggered inflation changed the distribution of active tectonic strain rates in the adjacent Central Walker Lane, east of the Sierra Nevada, effecting seismicity rates. Earthquakes occurred more frequently in places where the geodetic strain rates increased, suggesting that hydrological surface loading (e.g. from changing levels of aquifers, snow and lakes) affected the magmatic system in ways that subsequently influence earthquake occurrence. The study captures in new detail the complex links between between climate, active volcanos and earthquakes in eastern California and Nevada.

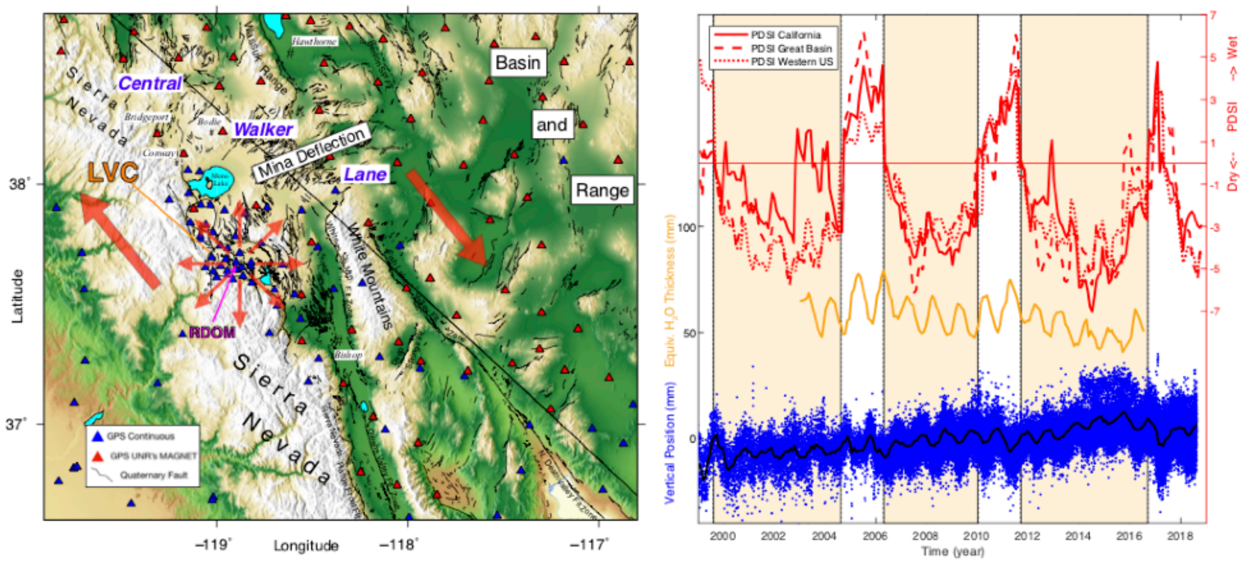

Figure 6 (above). (left) Map showing location of Long Valley Caldera (LVC) at the boundary between the eastern Sierra Nevada and central Walker Lane. The general sense of active crustal deformation from tectonics and magmatic inflation is given with the red arrows. MAGNET and continuous GPS stations are shown with red and blue triangles, respectively. (right) Time series of Sierra Nevada uplift compared to the Palmer Drought Severity Index (PDSI) which is an indicator of generally dry or wet conditions (red lines) and GRACE data that indicate integrated surface water mass changes (orange line). See text and Hammond et al., (2019) for further explanation. MAGNET data were essential for constraining the geographic extent of deformation east of LVC.

Following large earthquakes within the MAGNET footprint, NGL responds by moving GPS receivers in its instrument pool into its stations nearest the event epicenter. MAGNET data complement seismic data and help to understand the vigorous seismic swarms that strike the western Great Basin region roughly once a year. During this project period there were several earthquakes or significant swarms to which we responded. These include the 2014-2015 Sheldon swarm in northwest Nevada, the December 2016 Nine Mile Ranch sequence in the Central Walker Lane, the July 2019 Ridgecrest sequence, the March 2020 Carson City M4.5 earthquake, the April 2020 Mono Lake sequence, and the May 2020 Monte Cristo Range M6.5.

There are several goals to the geodetic responses, including obtaining better constraints on coseismic displacements by obtaining data immediately before and after the event. Responding quickly is important because it can become impossible to distinguish between pre-, co-, and post-seismic displacement if there are no data immediately before and after the main event. In practice it can be difficult to move instruments by hand using vehicles in some conditions. For example, in December 2016 the Nine Mile Ranch sequence occurred during a time when there had been heavy snow and roads were in poor condition, and also many staff and students were on winter holiday. However, we were eventually able to get instruments recording and constrained offsets sufficient to contribute to a study of stress transfer among individual events (Hatch et al., 2020).

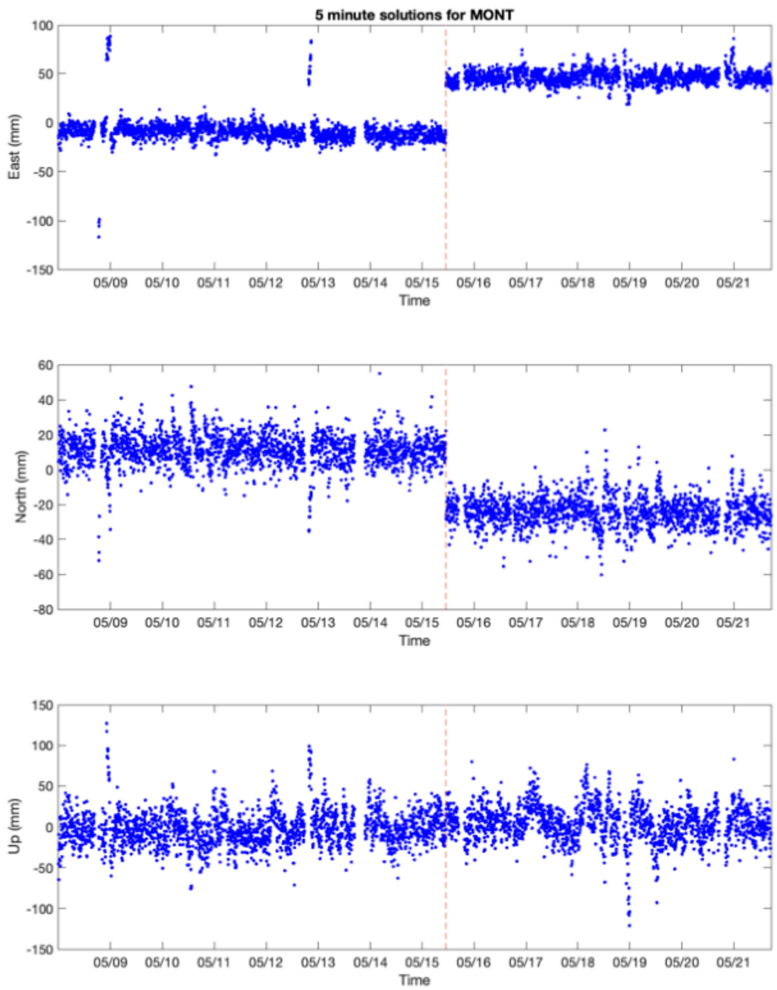

Figure 7. 5-minute sample rate time series from MAGNET GPS station MONT. The time of the May 15, 2020 Monte Cristo Range M6.5 earthquake with epicenter 17 km from this station is indicated with the vertical dashed line. These results show the clear horizontal offset attributable to coseismic displacement. Moreover, the data indicate that most of the permanent displacement occurred over a very short time period, within a single 5 minute time sample, and that any postseismic deformation was either non-existent or small by comparison.

Following the May 2020 Monte Cristo Range M6.5 earthquake, which occurred on a Friday morning, we were in the field moving receivers by the following Sunday. However, we had fortuitously been working in the epicentral area in early March and had deployed about a dozen receivers that were already recording in the area when the earthquake occurred. While as of this writing we are still gathering data for this event, we have already retrieved and processed data from some stations. These include station MONT which is 17 km from the epicenter. Five-minute time series from MONT clearly indicate the horizontal offset of 66 mm, and that very little postseismic deformation occurred within days after the event (Figure 7). The early horizontal coseismic offset pattern shows vector displacements that are consistent with a sinistral rupture on a ENE striking plane (Figure 8). Efforts to integrate geologic observations of surface rupture, seismic and InSAR data, into a model of the slip are ongoing.

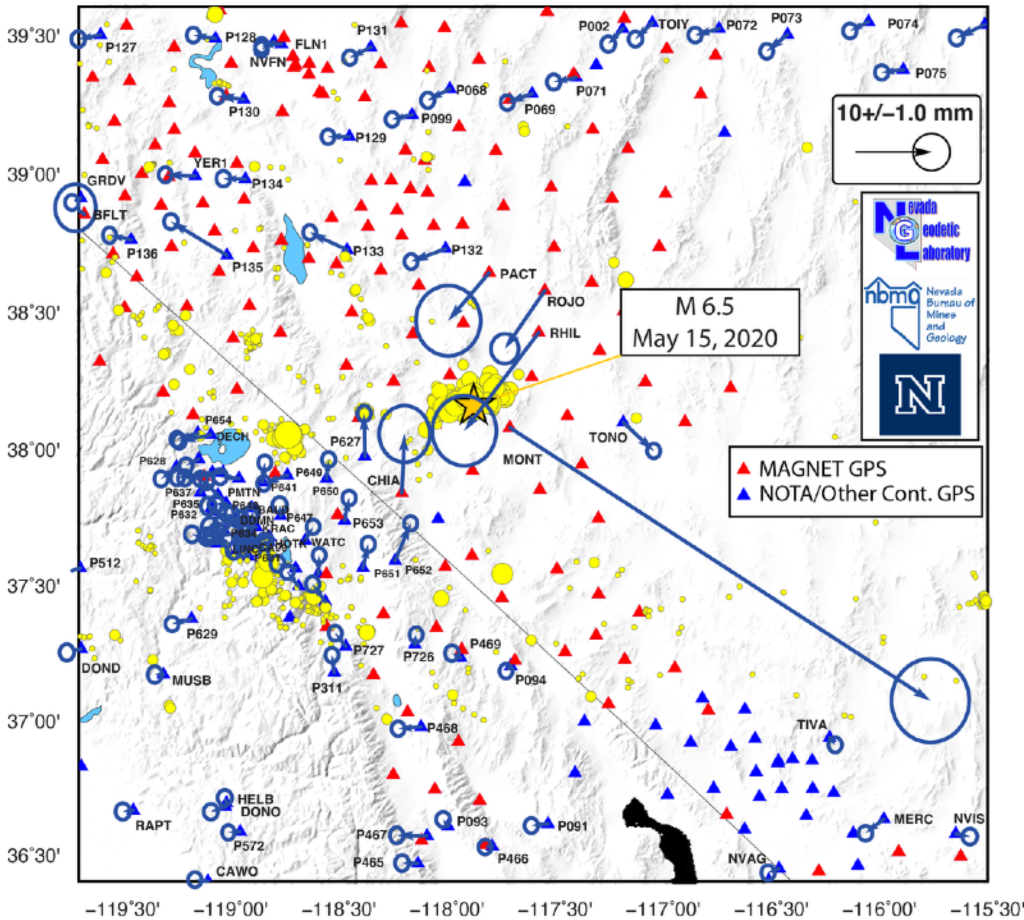

Figure 8. Preliminary coseismic displacement pattern for the May 2020 Monte Cristo Range M6.5 earthquake near Tonopah, NV. The nearest continuous station (P627) is about 50 km distant, whereas MAGNET has about a dozen stations within this radius. NGL is currently gathering data in the part of the MAGNET GPS network (red triangles) nearest the epicenter. As new data come in we will fill in the (likely larger) near-field displacements to complement those from the continuous stations (blue triangles).

Bibliography of publications resulting from the work performed under this award.

Reviewed Articles, Theses and Dissertations (in alphabetical order)

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